PILLINGER

Roof Truss Heel Joints

Architectural Engineering

B. S.

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ROOF TRUSS HEEL JOINTS

BY

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THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

ARCHITECTURAL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

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June 1, 1908

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

RALPH ALFRED PILLINGER

ENTITLED ROOF TRUSS HEEL JOINTS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

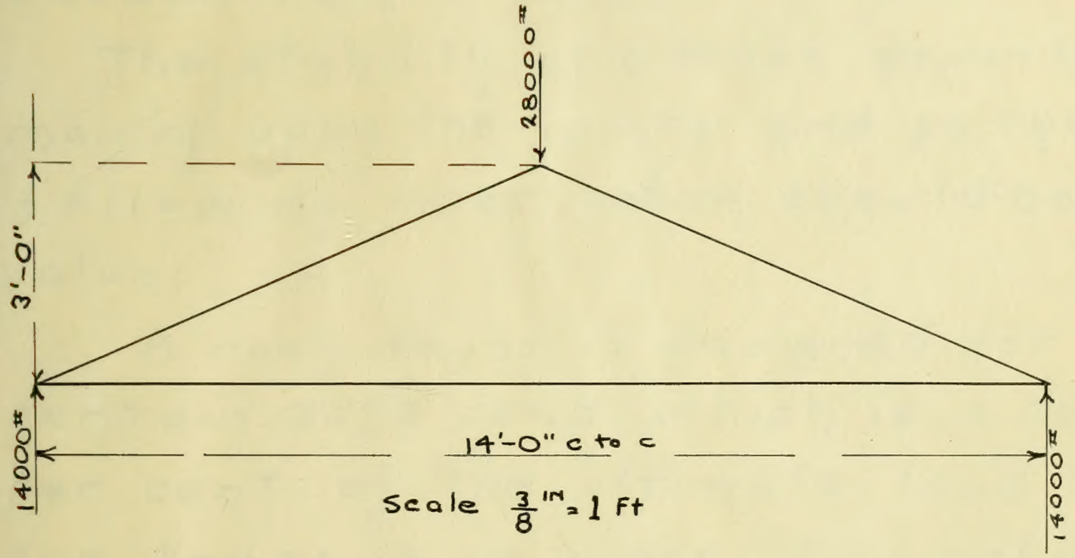
DEGREE OF Bachelor of Science in Architectural Engineering

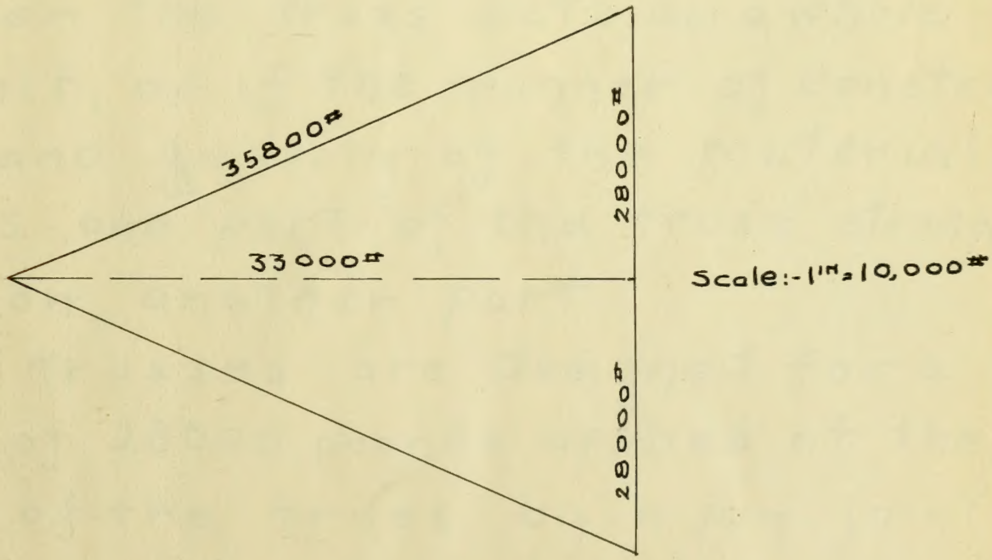
James M White.
Instructor in Charge.

APPROVED: N. Clifford Ricker.

HEAD OF DEPARTMENT OF Architecture

Detirmination of Stresses on Trusses-





Character and General Description

The object of this thesis is to investigate the principals which should really govern the design and construction of wooden roof trusses

The stability of a truss depends mainly upon the joints and so the following investigation should be of value.

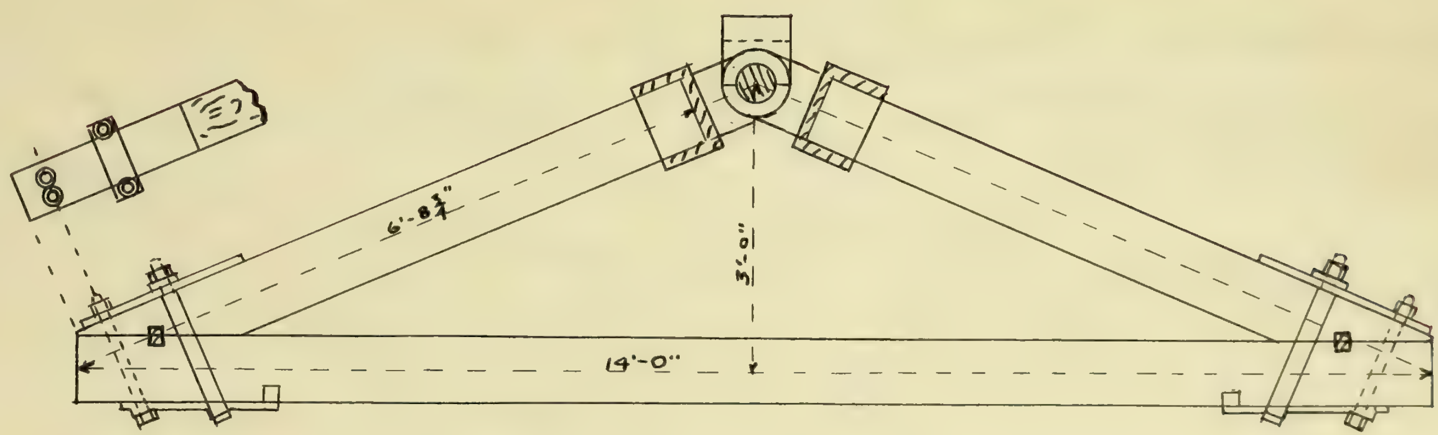
A roof truss is designed for a certain safe load which is a definite per cent of the ultimate load. When the truss is in place it is not known whether the truss acts as a whole - or unit, or if the manner of construction and quality of the materials makes one part of the truss stronger than another part

All trusses are designed for a load of 28000 pounds applied at the apex of the truss by a pin joint

The machine used will be the 600 000 pound Riehle machine in the Mechanics Laboratory.

DESIGN OF ROOF TRUSS NO-1-

Scale $\frac{1}{2}$" = 1 FT.



Design of Joint No-1-

This joint made of 2-$1\frac{1}{2}$ in-bolts, 1 steel key, 1 steel hoop, 1 steel and 1 cast iron plate

Upper Chord:- Assume 6"x 8" L.L.Y.P. timber

$L = 7.58'$ $d = 6" = \frac{1}{2}'$ $\frac{L}{d} = \frac{7.58}{.5} = 15.15$ Say $\frac{L}{d} = 15.$

Unit Stress - L.L.Y.P = 4020#/□" (Cambria)

Factor Safety = 5 ; Allowable Stress = 804#/□"

Sect. Area = 48□" Stress = ~~408~~ = 48 x 804 = 38,590#

Lower Chord:- Assume 6"x 8" L.L.Y.P. timber.

P = aS = ~~48 x 1200 = 57,600#~~ = 36 x 1200 = 45,000#

Upper Chord:- Allow. Str. = 38,590# ;- Act-Stress = 35,800#

Lower Chord:- " " = 45,000# ; " " = 33,000#

∴ 6"x 8" L.L.Y.P. timbers are O.K.

Let 120#/□" = Safe Shearing Stress

-Allow. Stress = 120# x 6" x 10" = 7200# = Str-taken-by-Key

33000# - 7200# = 25,800# = Stress left for bolts + strap

-Crushing on end by Key:- Allow = 1000#/□"

-Assume depth $1\frac{3}{4}$" - Area = 10.5□"; $\frac{7200\#}{10.5} = 685$#/□" = Act

-Computation of Bolts:- Str-Allow = 12,500#/□" tensile

67,700# = Stress parallel to bolts.

$\frac{67700}{12500} = 5.4$□" = bolt and Strap Area.

- Area - root thread of $1\frac{1}{2}$" Bolt = 1.3□"

∴ Use 2 - $1\frac{1}{2}$" Bolts - A = 2.6□"

∴ Use Strap - 2"x $\frac{3}{4}$" ;- A = $2 \times 2 \times \frac{3}{4} = 3$□"

So Total Area = 2.6 + 3 = 5.6□" = Sufficient

Design of Joint No 1 (contd.)

To obtain enough bearing area:—

Washer for Bolts: $\frac{2.6}{5.6} \times 67,700 = 31,400^{\#}$ = Stress

Bearing = $600^{\#}/\square''$:– $\frac{31400}{600 \times 6} = 8.7''$ Use-Washer-$9'' \times 6'' \times \frac{3}{4}''$

Washer for Strap: $67,700 - 31,400 = 36,300^{\#}$ = Stress

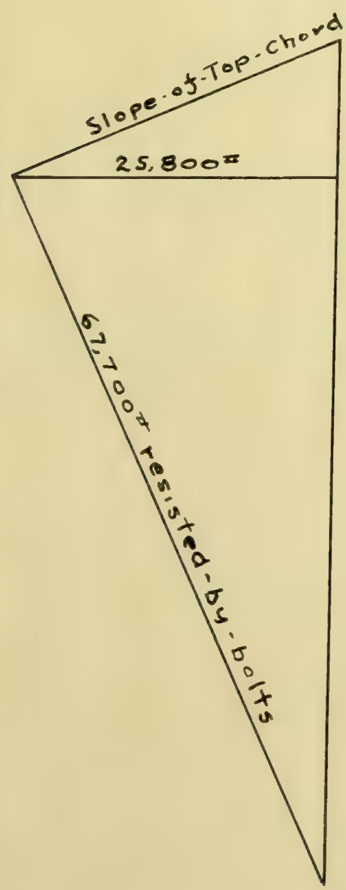
$\frac{36,300}{600 \times 6} = 10''$ Use a Washer:– $10'' \times 6'' \times \frac{3}{4}''$

Combine-2 Washers-in-one:– $20'' \times 6'' \times \frac{3}{4}''$

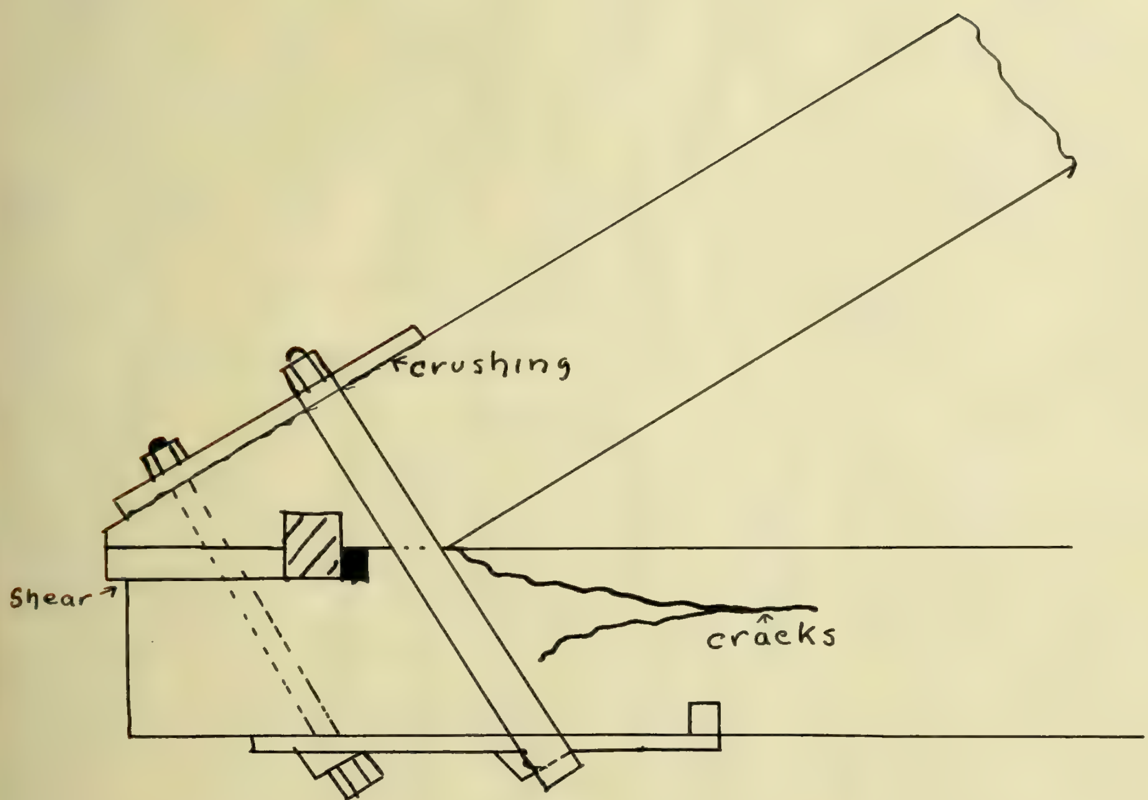
A-$1\frac{5}{8}''$ thread-upset on strap to fasten it-tightly

Crushing from lower plate – Allow = $1000^{\#}/\square''$

$120 \times 6 \times 25\frac{1}{2} = 18,380$ Stress = $13000^{\#}$; $\frac{13000}{12} = 1000^{\#}/\square''$



FAILURE OF JOINT NO 1



Joint No. 1

This truss consists of 6 x 8 inch long leaf yellow pine for the upper and lower chords. The joint was formed of 1 steel hoop $2 \times \frac{3}{4}$ inches, 1 - $20 \times 6 \times \frac{3}{4}$ inch steel plate, 1 - $20 \times 6 \times 1$ inch cast iron plate, 2 - $1\frac{1}{2}$ inch bolts and a key $6 \times 2 \times 3\frac{1}{2}$ inches.

The truss could not be perfectly centered at the theoretic points of support as the theoretic points of support were at the extreme ends of the truss, so the truss was supported about eight inches from the extreme ends of truss.

The load was applied gradually.

The load was run up to 47,000 pounds before any failure could be noticed. At this point the key sheared the extreme ends of the lower chord at the right end first, and shortly afterwards, at the left end, at a load of 49,000 pounds

Nothing else was noticed, except a slight noise of the strap and bolts taking hold of the added weight, caused by the ends shearing. When a load of 57 000 pounds had been reached, marked noises were heard

Continued

(Joint No 1 cont'd)

At the ends of truss, longitudinal displacement was now about $\frac{1}{2}$ inch. At about 65000 pounds a cracking was heard, and the lower chord started splitting at the intersection of the bottom of the upper chord, and the top of the lower chord. Truss finally failed by this splitting, at 67,500 pounds.

It is supposed that failure was caused by cross bending on account of the points of support not coinciding with the theoretical points of support.

The truss was designed for a load of 28,000 pounds, and failed at 67500 pounds, so that its factor of safety is 2.4.

$33000 \times 2.4 = 79,200^{\#}$ = tension in lower chord

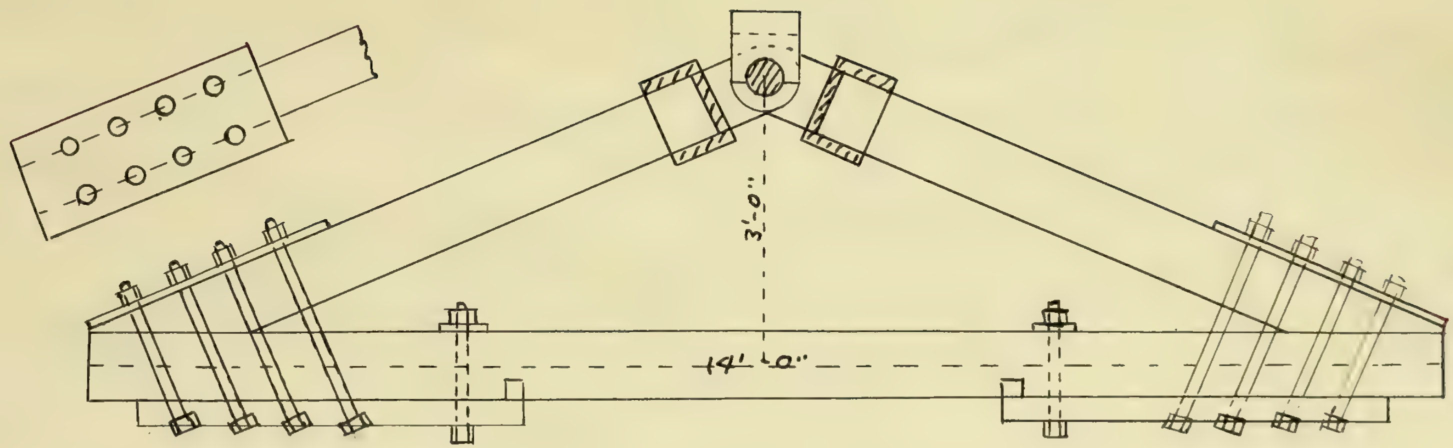
$880 \times 5 \times 37.5 = 165,000^{\#}$ = stress timber should carry

$\frac{79,200}{165000} = .48$ or lower chord failed at $\frac{1}{2}$ stress it would carry which shows cross-bending took place.

The bolts and strap were designed for $67,700^{\#}$ safe load. After key gave way there was $\frac{1}{4}$ more stress than bolts should carry

DESIGN OF ROOF TRUSS NO-2-

Scale $\frac{1}{2}$ in = 1 ft



Design of Joint No. 2.

This joint made by all bolts carrying stress running outside of timber

Joint has 8 Bolts; 1 small bolt; steel plate and cast iron plate

Upper Chord:- Stress = 35,800#

Lower " " = 33,000#

Str parallel to bolts = 85,000#;- Allow St = 12,500#/□"

$\frac{85000}{12500} = 6.8$ □" = bolt Area - A - $1\frac{1}{4}$" bolt = 0.89 □"

Use 8 - $1\frac{1}{4}$" Bolts - Area = 7.12 □"

Comp - of Plates for Bearing Area - Allow = 600#/□"

Width = $\frac{85000}{600 \times 6} = 23.6$" Use 24"x12"x1" - St. Plt

Depth of C.I. Plate - for Bending Moment.

$42,500 \times 3.75 - 42,500 \times 1.5 = 96000$

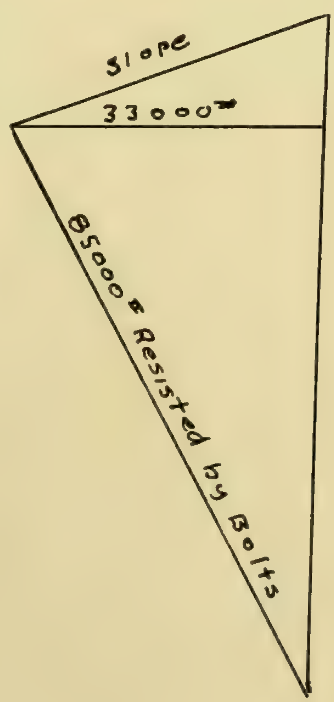
$\frac{96000}{12000} = d^2$

$d = 2.83$

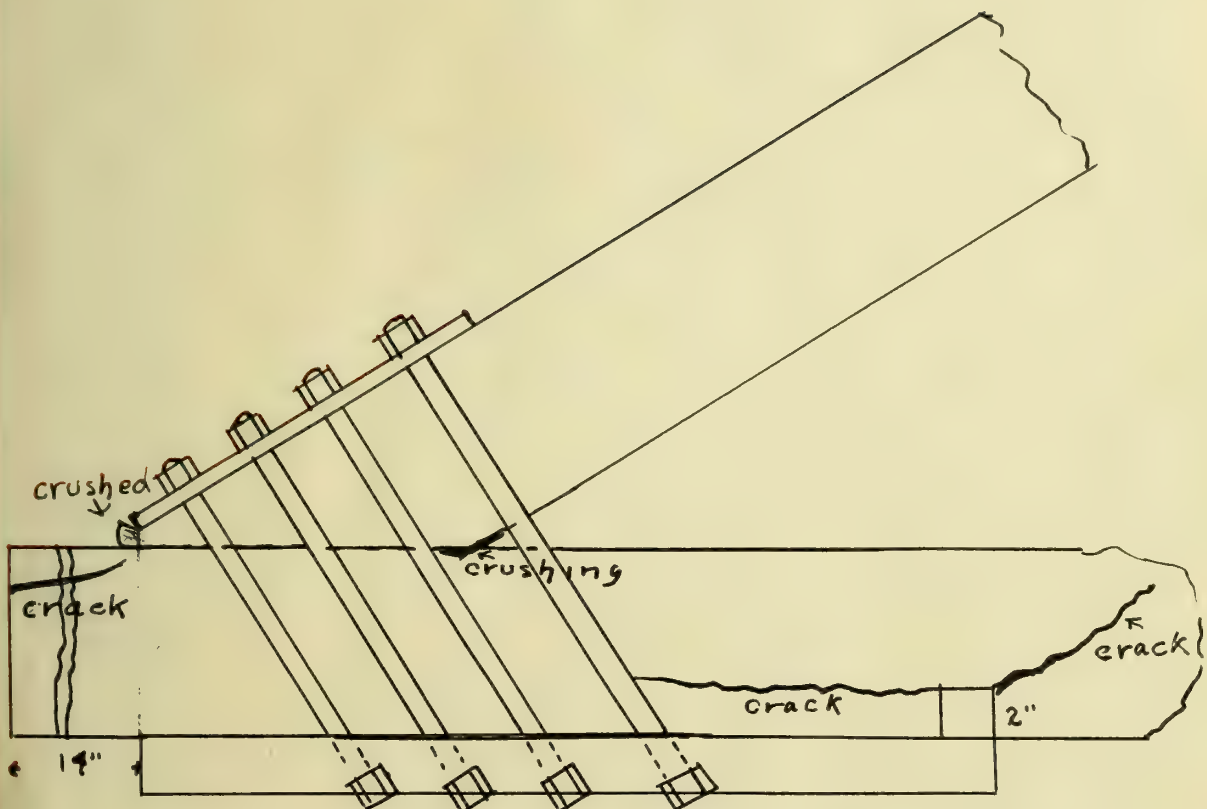
So make CI Plate

36" x 12" x 3"

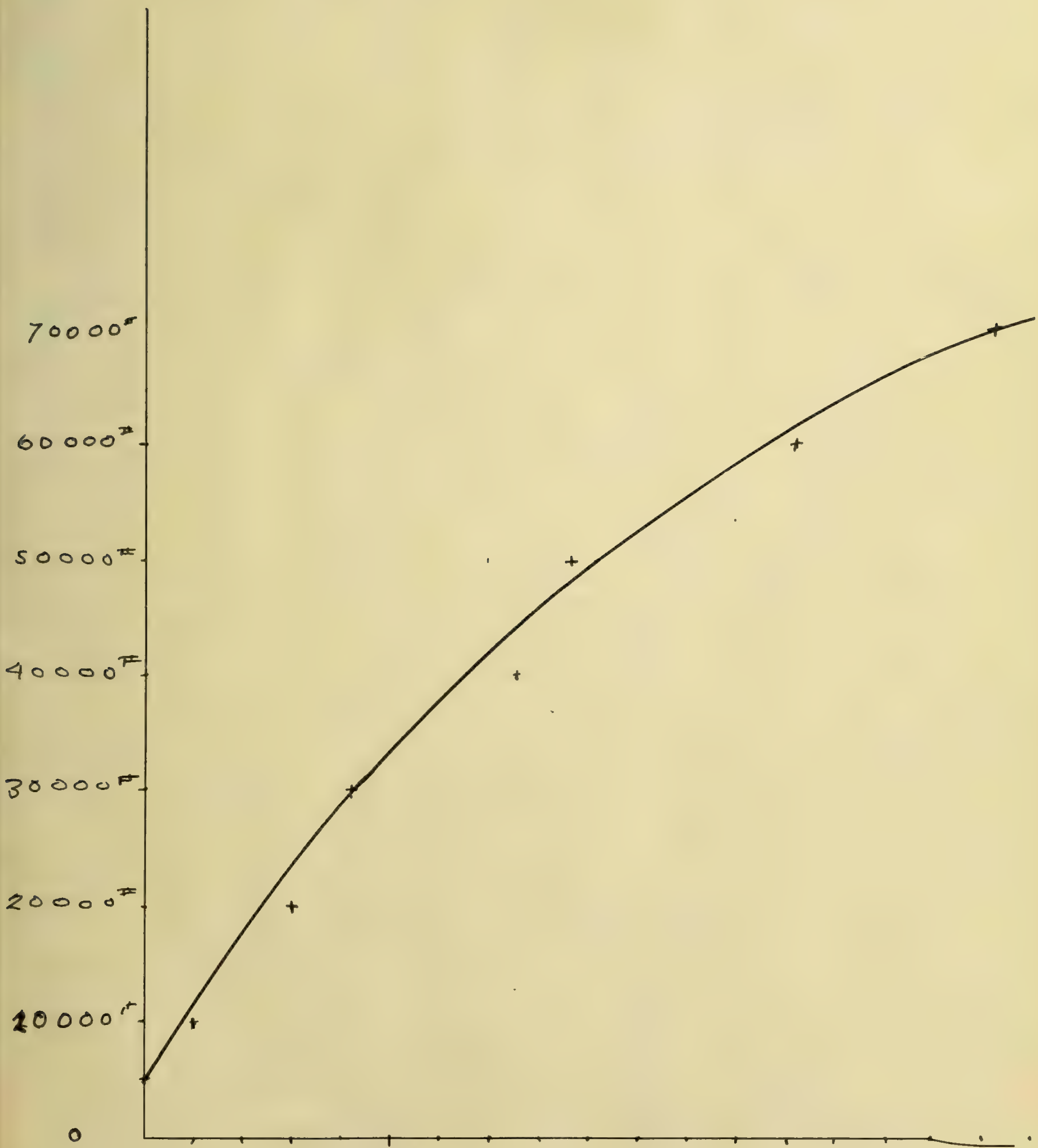
$\frac{7}{8}$" Bolt and Lug on CI plate assumes end crushing and shear on timber.



FAILURE OF JOINT NO-2-



Load-Deflection-Curve-Joint No 2



Joint No. 2.

This truss is composed of 6 x 8 inch long leaf yellow pine timbers for upper and lower chords.

The joint is formed of:–

8 - 1¼ inch bolts, 1 - 12 x 24 x 1 inch steel plate and 1 - 36 x 12 x 3 inch cast iron plate.

The truss was centered at the theoretical points of support.

The load was applied gradually and no failing at all was noticed for the first 40,000 pounds, except the crushing of the upper chords into the lower chord at the joints.

At 50000 pounds a crack was noticed extending from the upper edge of upper chord down and out to extreme end of truss. There was quite a little crushing of upper chord into the lower chord.

At about 55000 pounds the lower chord started cracking from the upper end of lug on right end of truss, over about ten inches.

At 60,000 pounds the lower chord started

Continued

(Joint No. 2 Cont'd)

cracking at left end of truss from upper edge of lug on casting upward and towards the center of truss. The truss failed at this joint at 65 000 pounds. At the time of failure, top chord was crushed at the intersection of its upper edge and the upper edge of lower chord. Also the upper chord crushed into the lower chord about one inch at intersection of lower edge of upper chord and upper edge of lower chord.

The truss was designed for 28 000 pounds.

It failed at 65 000 pounds, so its factor of safety is 2.32.

It is supposed that the lower chord failed by bending because the joint acted as a stiff joint and not as a pin joint as it was designed.

33 000 × 2.3 = 75 900 = tension in lower chord.

880 × 5 × 36 = 158,400# = stress it should carry

∴ this shows there was tranverse stress

Joint No 2 (Contd)

$6 \times 6 \times 880 \times 5 = 158,500^{\#}$ = tension lower chord can stand

$33000 \times 2.3 = 76000^{\#}$ = tension in lower chord when it broke

Deflection:-

$$P = \frac{48fEI}{l^3} = \frac{48 \times 1.45 \times 1,500,000 \times 108}{(14 \times 12)^3}$$

$P = 2370$ = load at center causing transverse stress

$$S = \frac{Mc}{I} = \frac{1}{4}\frac{Plc}{I} = \frac{6 \times 1185 \times 7 \times 12}{6 \times 6 \times 6} = 2765^{\#}/\square''$$

$$\text{Unit tension} = \frac{76000}{36} = 2100^{\#}/\square''$$

$2100 + 2765 = 4865^{\#}/\square''$ = stress in extreme fibre

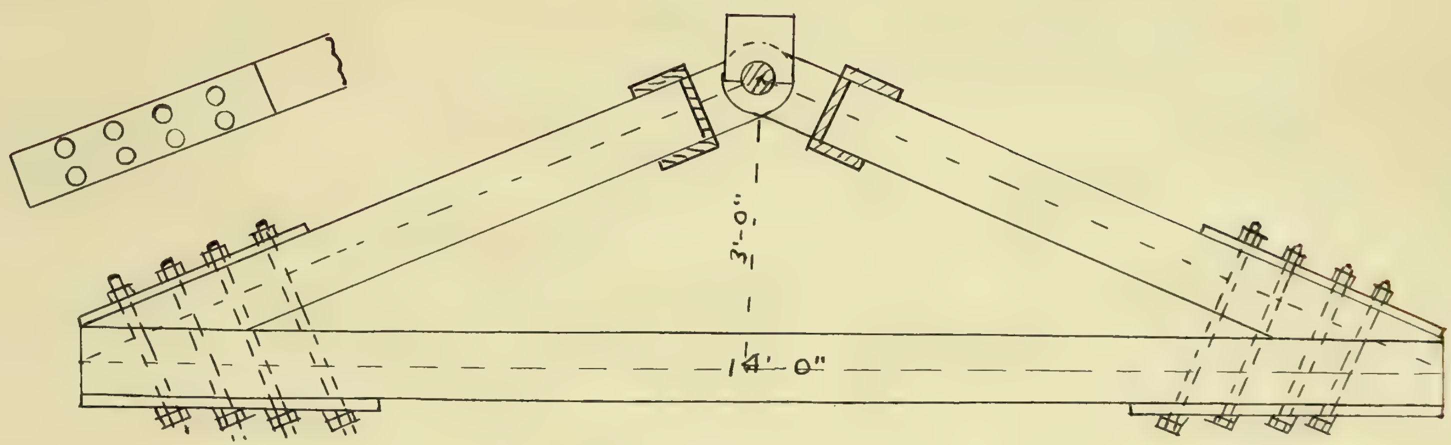
$880 \times 5 = 4400$ = ultimate tesion strength

$\therefore$ lower chord failed by a combination of tension + transverse stress

(see conclusion)

DESIGN OF ROOF TRUSS NO-3·

Scale:- $\frac{1}{2}$" = 1 FT



Design of Joint No. 3

Joint is similar to Joint No 2 except bolts run thru timber insted of outside them.

Joint has 8-$1\frac{1}{4}$" Bolts; 1 steel & 1 CI Plate

Stress parellel to bolts = 85,000#

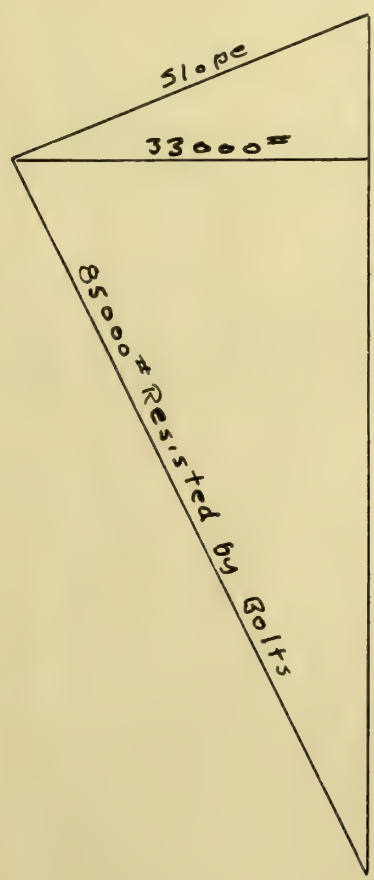
$\frac{85000}{12500}$ = 6.8 = Bolt Area :- A of $1\frac{1}{4}$" Bolt = 0.89□"

Use 8-$1\frac{1}{4}$" Bolts - Area = 7.12□"

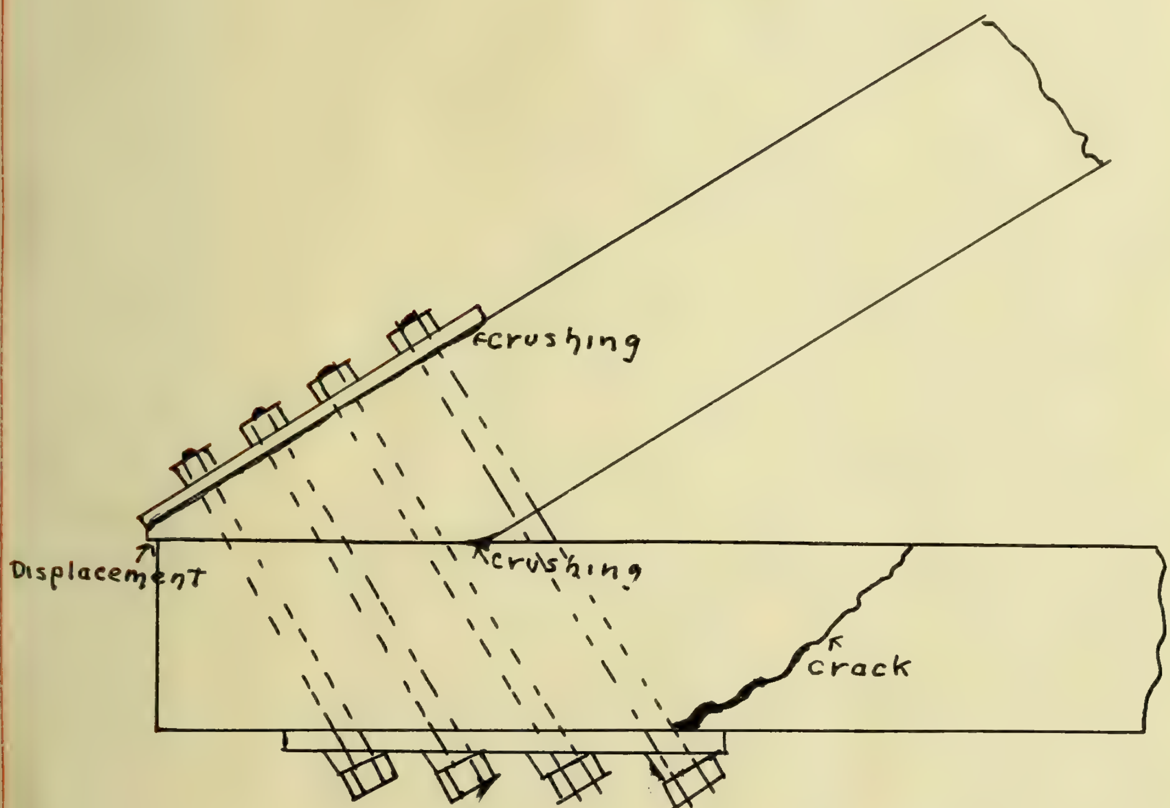
Comp - of Plates for Bearing - Allow = 600#/□"

width = $\frac{85000}{600 \times 6}$ = 23.6" Use 24"x6"x$\frac{3}{4}$" Plate-St.

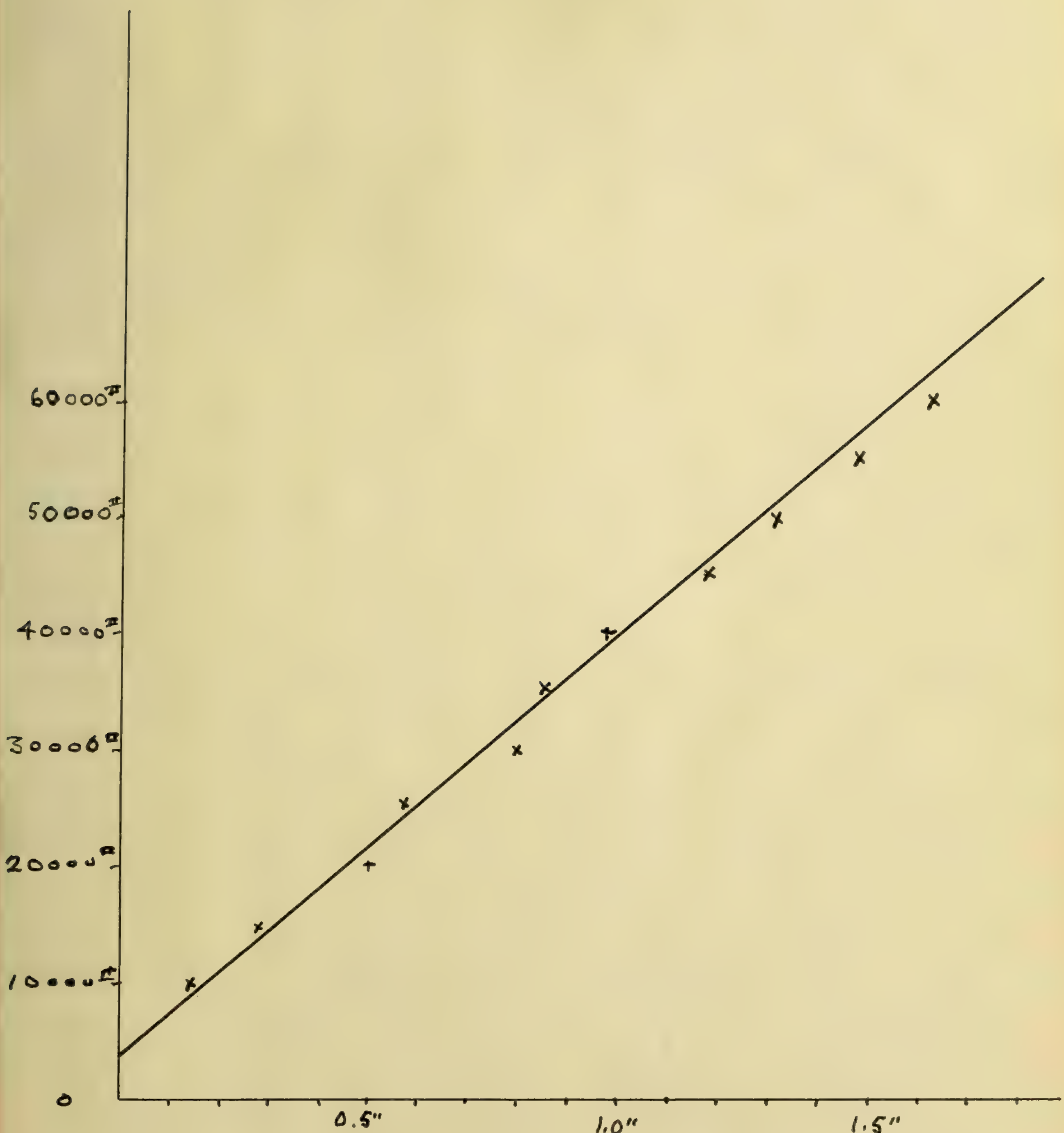
Make CI Plate 1" thick. " 24x6"x1" " -C.I.



FAILURE OF JOINT NO -3-



-Load-Deflection-Curve-Joint-No 3-



Joint No. 3.

Truss is formed of 6 x 8 inch L.L.Y.P. timbers. The joint is composed of 8 - $1\frac{1}{4}$ inch bolts; 1 - 24 x 6 x $\frac{3}{4}$ inch steel plate, 1 - 24 x 6 x 1 inch cast iron plate.

The points of support had to be taken 8 inches in from the theoretical points of support as theoretical points of support were at ends of truss.

The load was applied gradually. No signs of failure were noticed until 20000 pounds were reached. At this point the upper chord could be seen to be displacing longitudinally slightly on lower chord.

At 40000 pounds this displacement was $\frac{1}{2}$ inch. At 50000 pounds this displacement was about $\frac{3}{4}$ inch.

At 60000 pounds a crack started at inside end of plate on lower chord and went upwards toward the center until truss failed at 62000 pounds.

After joint was taken apart it was noticed that bolts had bent, while upper chord had been displacing

The supposed reason for failure is;— either that points of support being inside true points of support, the truss broke by the bending movement thus created; or that the joint acted as a rigid joint and not as a pin joint, and the lower chord failed by tension at its weakest points where the area was reduced by the bolts.

Truss was designed for 28000 pounds. It failed at 62000 pounds, so its factor of safety was 2.21.

$33000 \times 2.2 = 72600^{\#}$ = tension - lower-chord

$880 \times 5 \times 36 = 158{,}400^{\#}$ = stress - should be carried

$\therefore$ lower chord failed at $\frac{1}{2}$ of what it should fail which shows cross-bending took place.

see next page

Joint No 3 contd

Tension = 158400# = stress lower chord should carry

" = 72,600# = " " " carried

Deflection:–

$$P = \frac{48fEI}{l^3} = \frac{48 \times 1.51 \times 1{,}500000 \times 108}{(12.66 \times 12)^3}$$

$$P = 3360\#$$

$$S = \frac{Mc}{I} = \frac{1Plc}{4I} = 3550\#/\square''$$

$$\frac{P}{A} = \frac{72600}{36} = 2000\#/\square''$$

$3550 + 2000 = 5550\#/\square''$ = stress-in-extreme fibre

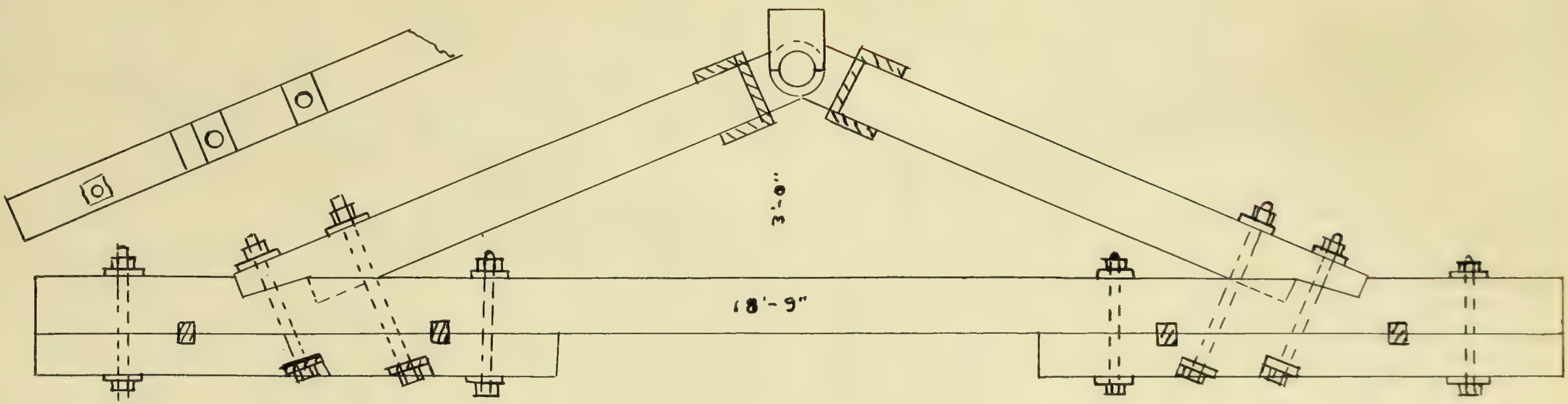
$880 \times 5 = 4400\#/\square''$ = allowed tension/□"

∴ lower chord broke by bending and tension

(see conclusion)

DESIGN OF ROOF TRUSS NO-4-

Scale: $\frac{1}{2}^{\text{in}} = 1^{\text{FT}}$



Design-of-Joint-No-4-

This joint is better for larger and heavyier work than preceeding joints -Joint will be made of 2 large bolts 2 small bolts;- 4 small plates; 2 steel-keys

Shearing-Str = $120 \times 6 \times 29\frac{1}{2} = 21,240^{\#}$

Bearing-area = $2'' \times 6'' = 12^{\square''}$

$$2\frac{1}{2}'' \times 4'' = \underline{10^{\square''}}$$
$$22^{\square''}$$

$\frac{21,240}{22} = 965^{\#}/_{\square''}$ Allow Str = $1000^{\#}/_{\square''}$

$33000^{\#} - 21240^{\#} = 11,760^{\#}$ left for bolts

Stress parellel to bolts = $30,000^{\#}$

$\frac{30000}{12500} = 2.4^{\square''}$ = bolt Area

Area $1\frac{1}{2}''$ bolt = $1.3^{\square''}$ 2 bolts = $2.6^{\square''}$ = sufficient

Plates for bearing area - Allow $600^{\#}/_{\square''}$

$\frac{30000}{600 \times 6} = 8.33$

Use 2 Plates - $4\frac{1}{2}'' \times 6'' \times \frac{3}{4}''$

The horizontal comp-of-stress transmitted from bolts to tension member by means of steel keys - 20" from end

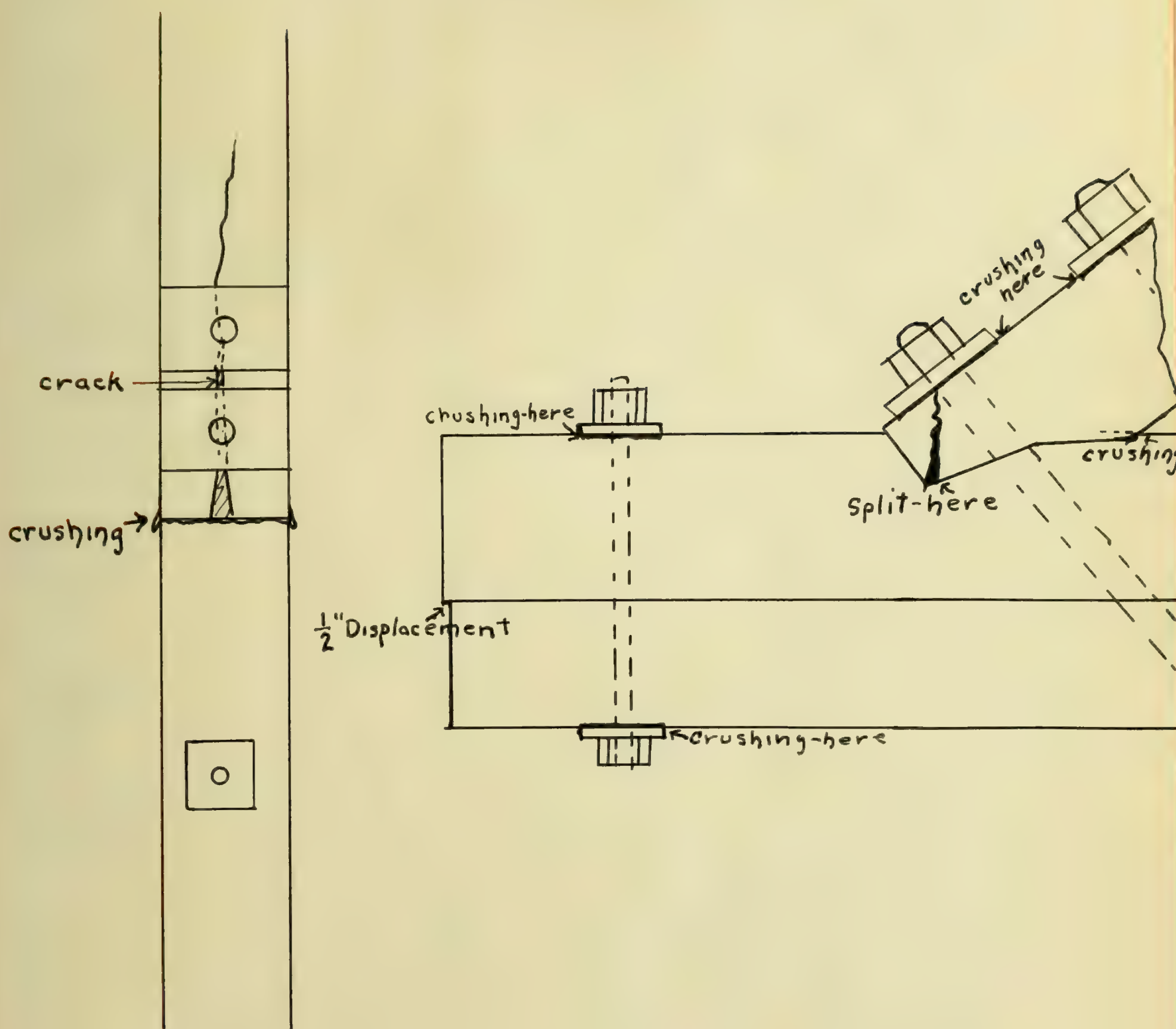
Sh-Str - $20 \times 6 \times 120 = 14,400^{\#}$

Use 2"x2"x6" Steel Key

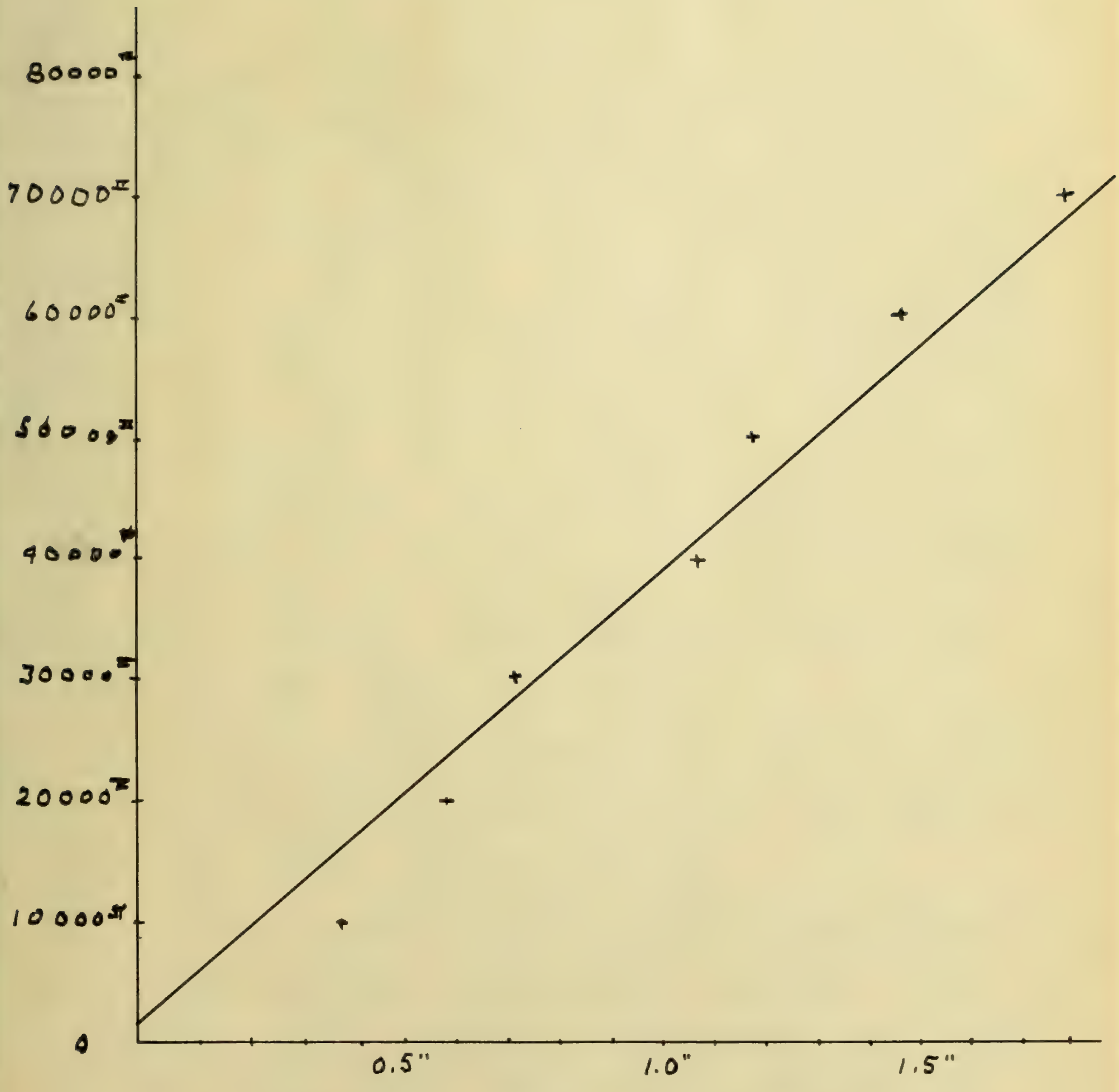
Bearing A = $2 \times 1 \times 6'' = 12''$

$\frac{11,760}{12}$ = less than $1000^{\#}/_{\square''}$

FAILURE OF JOINT NO. 4.



Load Deflection Curve Joint No. 4.



Joint No. 4.

This truss was formed of 6x8 inch timbers. The joint was composed of 2-$1\frac{1}{2}$ inch bolts; 1 steel key 6 x 2 x 2 inches, 4-6 x $4\frac{1}{2}$ x $\frac{3}{4}$ plates. The top chord was tenoned into the lower chord.

The truss was centered and supported at the theoretical points of support. The load was applied gradually. No signs of failure were noticed until 60000 pounds were reached, except the slight crushing of the top chord into the lower one. At 60000 pounds a crack started in the lower end of the top chord and grew larger. This crack was made by the pressure of the bolts on the wood.
The top chord also crushed from top of bolt nearest outside end of truss to top of the lower chord.
As the load increased, the compression of the top chord into the lower chord increased. The truss finally failed at 75000 pounds. The longitudinal displacement of the top chord on the

Joint No. 4 Cont'd.

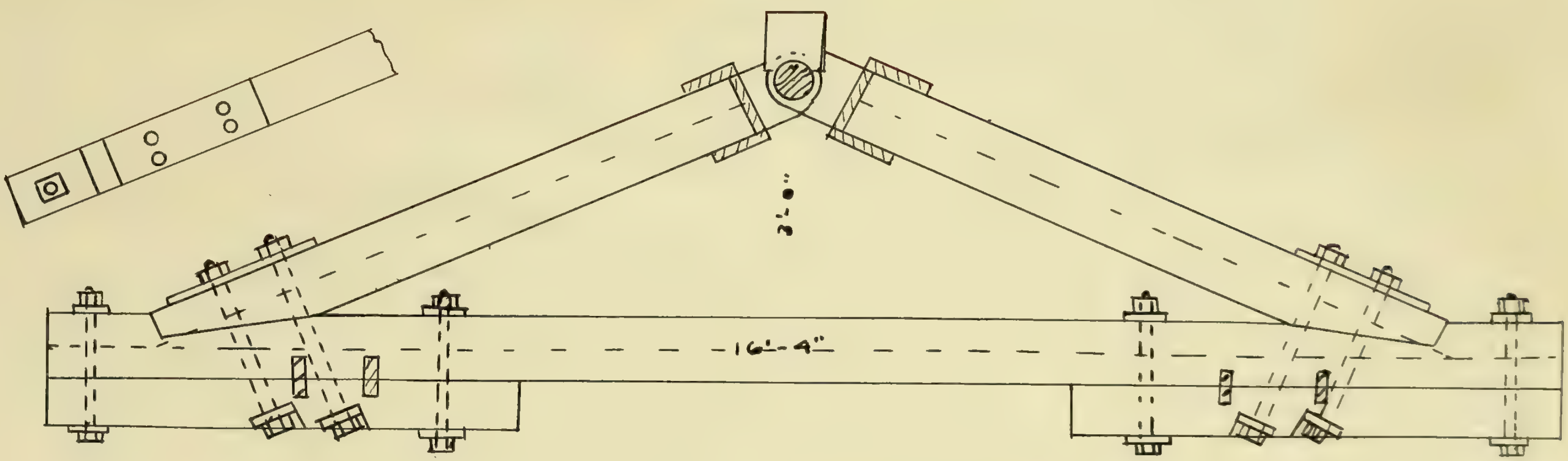
lower chord was $\frac{1}{2}$ inch.

All that can be said of the failure is that the joint failed completely and in the manner that was suspected.

The truss was disigned for 28000 pounds. It failed at 75000 pounds, so its factor of safety was 2.68.

DESIGN OF ROOF TRUSS NO-5-

Scale:- $\frac{1}{2}$ IN = 1 FT



Design of Joint No. 5

This joint has 4 large bolts; 2 small bolts; 2 steel keys and 3 plates

Sh-Str = 15" × 6" × 120 = 10 800#

33000 − 10 800 = 22,200#

57000# = Resisted by bolts.

$\frac{57000}{12500} = 4.56\square''$ = bolt Area   A - $1\frac{1}{2}''$ bolt = $1.3\square''$

$4 \times 1.3 = 5.2\square''$ sufficient

Use $6'' \times 4'' \times 1\frac{1}{2}''$ Steel Key

Tension Member to resist Shear; $L = \frac{22200}{6 \times 120} = 30.8''$

Bearing Pt for Bolts:–

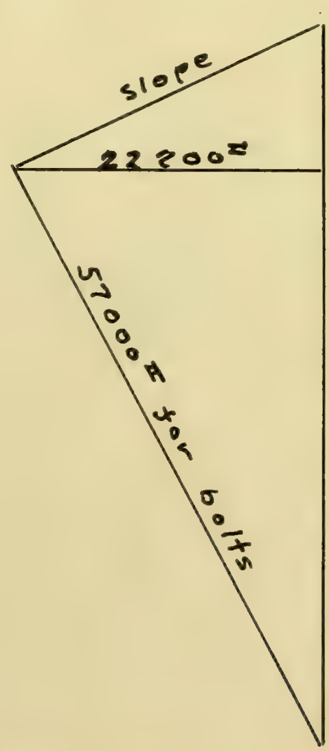
$\frac{57000}{600 \times 6} = 16''$ Use upper plt – $16'' \times 6'' \times \frac{3}{4}''$

" 2-lower " $8'' \times 6'' \times \frac{3}{4}''$

Bearing Area on Lower Keys

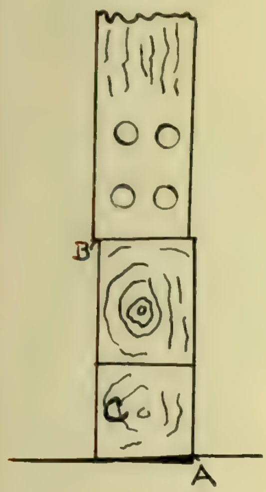
$2'' \times 2'' \times 6'' = 24''$

$\frac{22,200}{24}$ = less than 1000#/□"



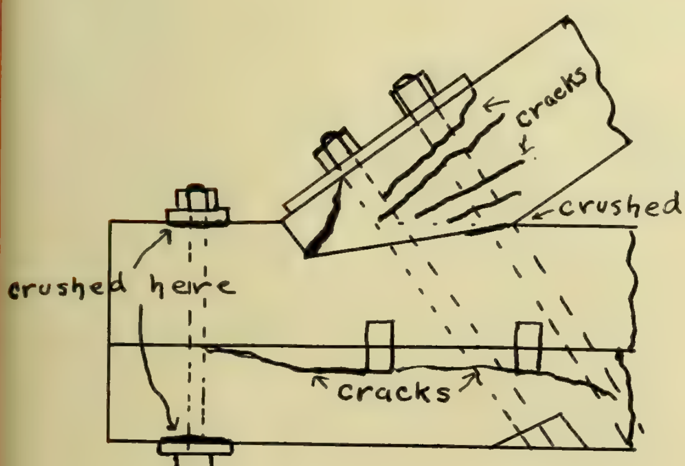
FAILURE - OF - JOINT - NO - 5.-

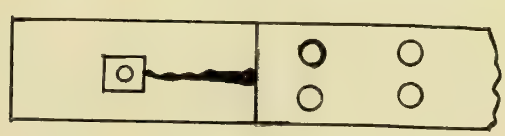
First - test



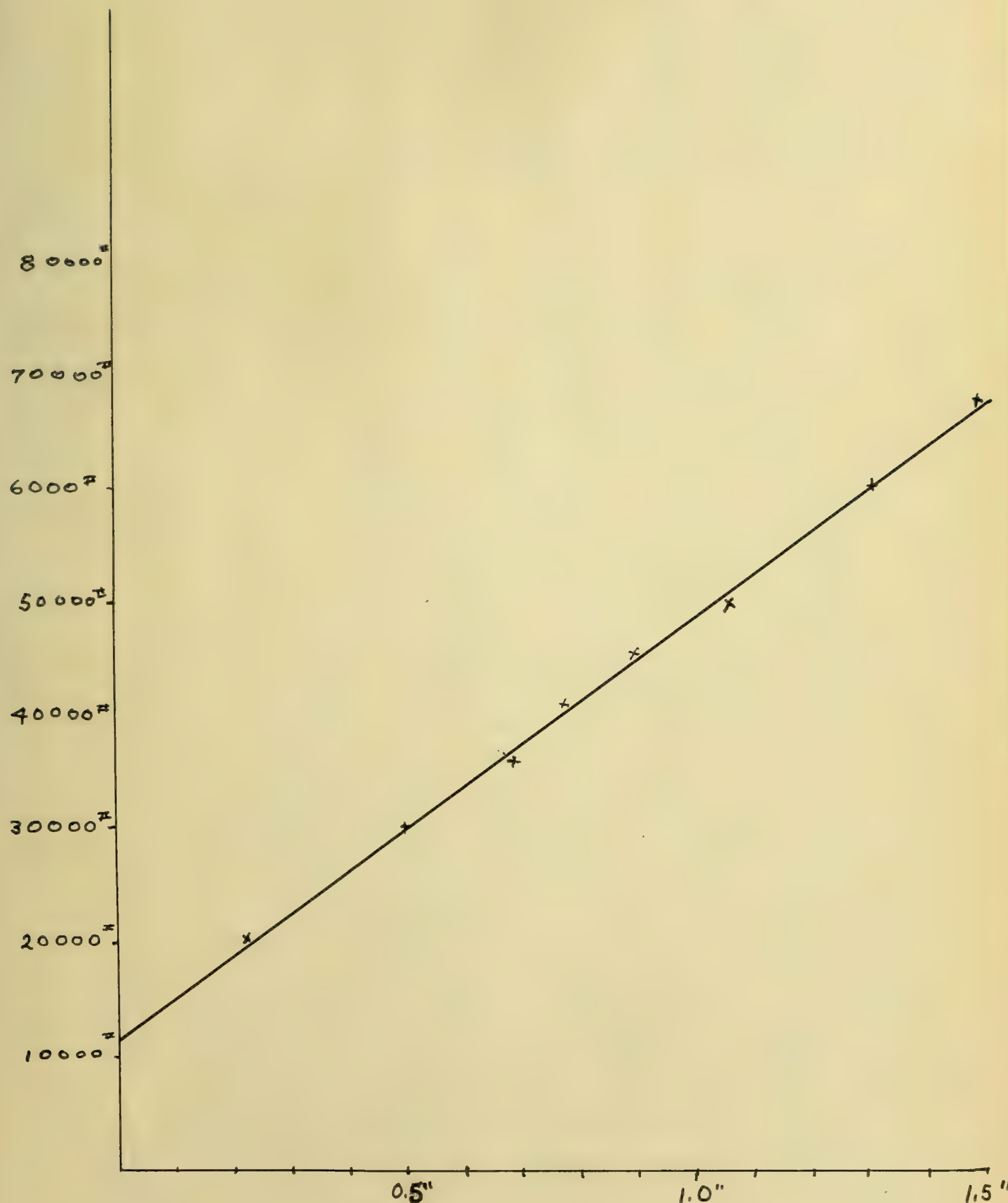
Timber (C) was not long leaf pine and so crushed at (A) causeing displacement at (B) which was $1\frac{1}{8}$"

Second Test





Load Deflection Curve Joint No. 5.



Joint No. 5.

This truss was composed of 6 x 8 inch timbers. The joint was composed of:–
4 – $1\frac{1}{2}$ inch bolts, 1 – 16 x 6 x $\frac{3}{4}$ inch plate, 2 – 8 x 6 x $\frac{3}{4}$ inch plates and a 6 x 4 x $1\frac{1}{2}$ inch key of steel.

The truss was centered and supported at its theoretical points of support.
The load was applied gradually.
The upper chord did not fit tightly into the lower chord. This open joint grew tight at 20,000 pounds. No signs of failure were noticed until about 40,000 pounds, when it was noticed that bearing piece of 6 x 6 inch timber attached to lower chord, was beginning to crush.
As this crushed, the truss began to warp, under the load. At 67,000 pounds it was found that no more load could be applied on account of the warp, so machine was taken off, and it was found that the 6 x 6 inch timber that crushed, was not long leaf yellow pine, but a very soft grade of pine. Truss was taken

(Joint No. 5 cont'd)

apart and pieces of real long leaf yellow pine were put on in place of defective ones.

Truss was again put in machine and load applied. No signs of failure were noticed, until 60000 pounds were reached. Here cracks started on the sides of the lower ends of the upper chords. A crack started on the extension of the lower chord. The keys started shearing on the piece of 6x6 inch.

The joint finally failed at the load of 70 000 pounds.

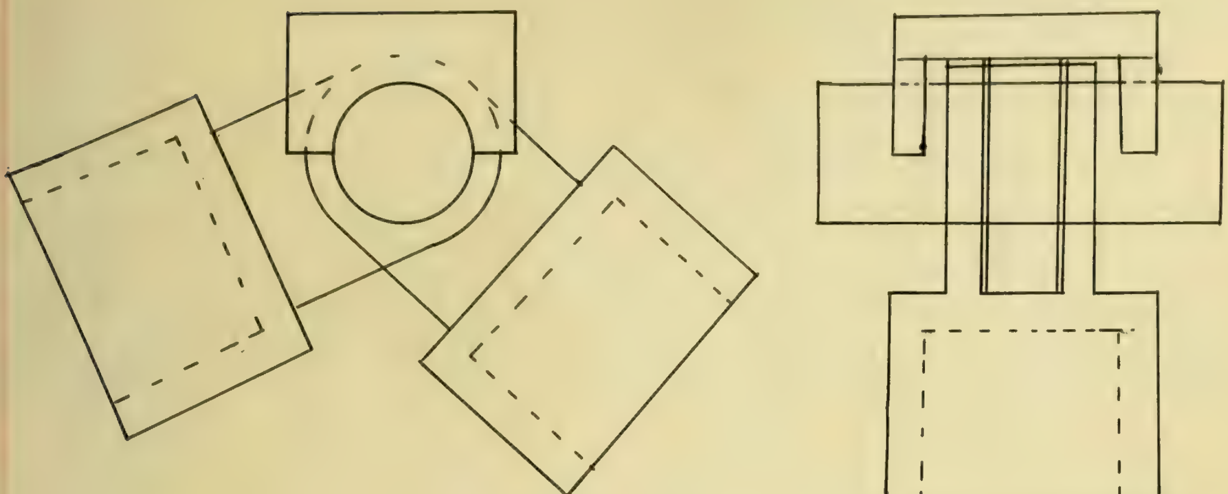
This joint failed completely and at several points at once.

The truss was designed for 28 000 pounds. It failed at 70 000 pounds, so its factor of safety was 2.5.

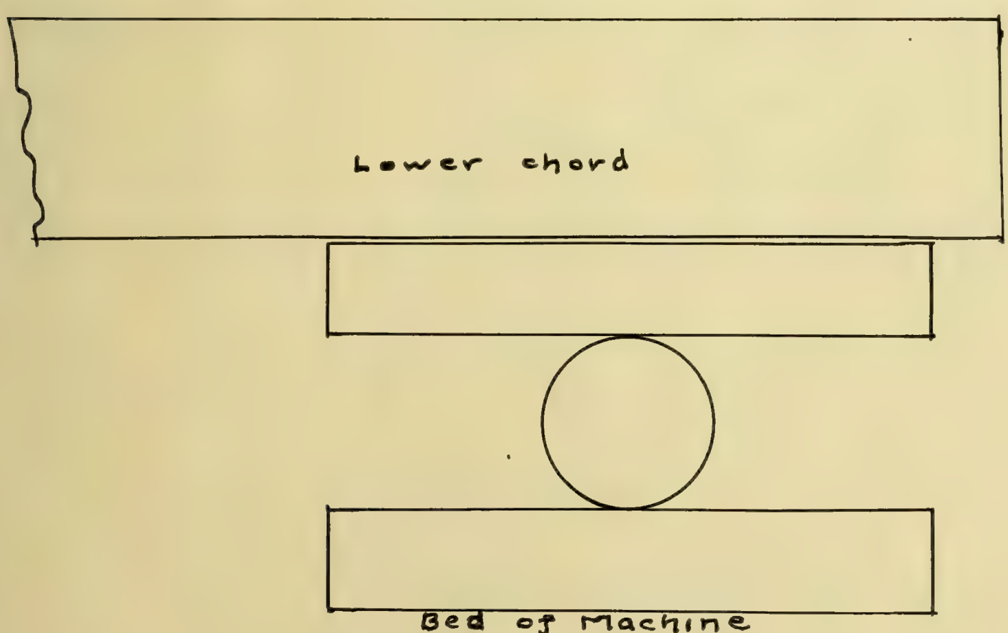
Contrivance Used to Test the Trusses.

A pin joint was used at the apex of the truss for the purpose of transmitting the direct stress into two equal components parallel to the upper chords.
A roller was placed under each end of the truss and a bearing plate balanced on top of the rollers, so as to allow a perfectly free bearing.
The load was applied through the head of the machine by a cast iron saddle piece which rested on the pin and applied the stress equally.

CONTRIVANCE-USED-TO-TEST-THE-TRUSSES



At Apex



At Supports

Test Pieces from Trusses.

A number of pieces of timber were taken from the failed trusses, and were tested for both Compression and Tension.

Average of tension tests; - Unit stress = 880 #/□"

Assumed Unit Stress Tension = 1200 #/□"

Average of Compression tests; Unit stress = 3451 #/□"

Assumed Unit Stress - Compression = 4020 #/□"

The above shows that timbers were not up to the average value given by the authorities for long leaf yellow pine and that the average L.L.T.P timber on the market is only about $\frac{3}{4}$ as strong as values authorities give.

Comparative Value of Joints.

Joint No. 1 is one of the simplest joints and stands a good test. The construction work is not expensive and the cost of joint is fairly cheap.

Joint No. 2 is an innovation in the construction of trusses. No bolts at all go through the truss to weaken the joint. This joint costs practically nothing to construct, and stands a good test but looks awkward.

Joint No. 3 is practically the same as Joint No. 2, except in No. 3 the bolts run through the timber. This weakens the timber & makes the cost of construction heavy. It stands a good test. Joint No. 4 is a type of truss construction for heavy loads. It is a very strong joint, being the strongest tested. It is not especially expensive to build and is a good type.

Joint No. 5 is on the order of No. 4 but is more expensive to construct and for the material. It stands a good test.

Conclusion

The results of these experiments show that any one of the tested joints is safe enough for practical purposes, since the factors of safety average 2.5

The results also show that ordinary long leaf pine timber is not as strong as it is supposed to be, that is, the timber which is called " long leaf yellow pine in this vicinity

None of the joints showed any signs of failure when the load for which they were designed was reached

When trusses are designed to be supported at the theoretical points of support they should be supported there, or the true value of the joint cannot be really determined

Keys used in combination with bolts are useless as the keys shear the wood before the bolts take hold and so the whole stress is put on the bolts

Conclusion

In the lower chord transverse stress existed and was, combined with tension, the cause of some of the failures. The cause of the transverse stress is that the truss joints acted as fixed connections and not as pin joints. The other cause of transverse stress is that the trusses, that is, some of them, could not be supported at the theoretical points of support

The reason a free end formula was used in the investigation of the transverse stress is that when the load was applied, the lower chord took the curve of a freely supported simple beam. The reason of this curve is that, although the ends are more or less restrained, the load, causing the bending, is not applied at the center of the beam, but at the ends.

It is a point of conjecture whether the truss should have ~~beem~~ been supported at the theoretical point of support

Conclusion

It is thought that if the point of support had been taken at a certain point inside of the theoretical support, the bending would have become zero.

It may also be that if the truss had been rested on flat supports; such as we would find in practice, and at a certain distance from the end of the truss, it may be that the bending moment would become zero.

With the conditions that we have in the present series of tests it would have been correct to have designed the timbers for transverse stress as well as tension.

Figured for tension only as done in fore-going work the reduced section was 36", making the whole section a 6" x 8" timber

Now taking in the transverse stress, the design of the proper size of timbers will be taken up